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Population structure and antibiotic resistance of Acinetobacter DNA group 2 and 13TU isolates from hospitals in the UK

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A total of 287 Acinetobacter isolates belonging to DNA groups 2 (A. baumannii) and 13TU was collected consecutively from 46 hospitals and typed by randomly amplified polymorphic DNA fingerprinting with primers DAF-4 and ERIC-2. With a similarity coefficient of ≥72% as a cut-off value, 37 clusters of genotypically similar isolates (genotypes) were recognised. Four major clusters, found in 15, 12, 12 and 8 hospitals respectively, accounted for 42% of isolates, but only three of these predominant clusters were associated with outbreaks of infection in individual hospitals. Many of the isolates were resistant to multiple antibiotics, including expanded-spectrum β-lactam agents, aminoglycosides, tetracyclines and fluoroquinolones, but >98% remained susceptible to carbapenems and colistin. Overall, the study demonstrated that a heterogeneous population of Acinetobacter DNA group 2 and 13TU isolates, frequently showing multiple resistance to antibiotics, was causing infections in UK hospitals, and that four predominant genotypes appeared to have disseminated among geographically distinct locations.

Introduction

During the past 25 years, certain species belonging to the genus Acinetobacter have emerged as important causes of nosocomial infection, particularly ventilator-associated pneumonia, bacteraemia, secondary meningitis and urinary tract infections [1]. A recent European study found that Acinetobacter spp. are the eighth most common cause of nosocomial pneumonia [2]. DNA group 2 (A. baumannii) accounts for the vast majority of these cases [2] and is the genomic species that has been associated most frequently with outbreaks of colonisation and infection in hospitals [1]. Isolates belonging to the closely related DNA group 13TU (not yet given a species name) have also been implicated in a number of outbreaks in intensive care units (ICUs) [1]. Infections caused by A. baumannii and 13TU strains can be extremely difficult to treat because the bacteria frequently possess multiple antibiotic resistance mechanisms and have a propensity to spread between patients. Therefore, efficient control of Acinetobacter outbreaks is a major challenge for infection control teams. Future control requires knowledge of the population structure of these organisms so that the dynamics of spread of endemic and epidemic strains can be investigated and appropriate control measures can be introduced.

Against this background, the main aim of the present study was to determine the overall population structure of a large collection of clinically significant Acinetobacter DNA group 2 and group 13TU isolates obtained from 46 hospitals in the UK. Numerous different molecular methods have been used to type isolates of Acinetobacter spp. [1, 3, 4], but the large number of isolates to be examined in this study necessitated the use of a rapid and simple typing technique. Randomly amplified polymorphic DNA (RAPD) fingerprinting was chosen because it has been shown to be particularly useful and reproducible with isolates of Acinetobacter spp. [4–6]. The study also aimed to correlate the population structure with antibiotic

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resistance data to determine whether specific resi-
tances were associated with the ability of particular
strains to cause outbreaks.

Materials and methods

Bacterial strains

As part of a larger survey of antibiotic resistance in
Acinetobacter spp. by the Public Health Laboratory
Service [7], 287 isolates belonging to DNA groups 2
and 13TU were obtained from clinical specimens in 46
hospitals throughout the UK between Nov. 1999 and
Jan. 2001. Each hospital collected up to 25 consecutive
isolates of Acinetobacter from clinical specimens.
Demographic data such as patient age, sex, site of
isolation and ward type were collated at the Antibiotic
Resistence Monitoring and Reference Laboratory,
Central Public Health Laboratory, London. Replicate
isolates from individual patients were excluded, but
some isolates were stated by the collecting hospitals to
be associated with outbreaks of infection, whereas
others were from sporadic cases. Initial identification
of isolates to the genomic species level was by tDNA
fingerprinting, as described previously [8], except that
amplification products were separated through agarose
1.5% w/v gels at 120 V/200 mA and were visualised by
staining with ethidium bromide 5 mg/L for 30 min.
Discrimination between genomic species 2 and 13TU
was confirmed by amplified fragment length poly-
morphism (AFLP) fingerprinting [9]. Strain RUH 2037
(kindly supplied by Dr L. Dijkshoorn, Leiden Uni-
versity Medical Centre, The Netherlands) was used as a
reproducibility control in RAPD experiments.

Susceptibility testing

Antibiotic MICs for each isolate were determined as
part of a previous study [7]. Interpretation of antibiotic
susceptibilities was with the breakpoints recommended
for Acinetobacter spp. and Enterobacteriaceae by the
British Society for Antimicrobial Chemotherapy
(BSAC) Working Party [10, 11]. An exception was
sublactam, for which, in the absence of a BSAC
breakpoint, resistance was defined by an MIC of
\(\geq 16\) mg/L [12].

RAPD fingerprinting

RAPD fingerprints were generated with primers DAF-4
and ERIC-2, as described previously [13]. Amplifica-
tion products were separated through agarose 2% w/v
gels at 120 V/200 mA, with bromophenol blue as the
tracking dye. An external reference standard (100-bp
dna ladder; Amersham Pharmacia Biotech, Little
Chalfont, Bucks) was run in every sixth track of each
gel. DNA fragments were visualised by staining with
ethidium bromide 5 mg/L for 30 min once the tracking
dye had migrated for 10 cm. Gels were recorded and
stored as tagged image files with UVIsave image
capture equipment (UVitec, Cambridge, Camb).
to 2000 bp. Each isolate tested yielded a reproducible fingerprint pattern with DNA extracts prepared on different days. For DAF-4 RAPD, the molecular size marker standards from different gels clustered at ≥82.3% similarity with a band position tolerance of 1% (i.e., above the proposed cut-off value of ≥72% similarity for defining unrelated genotypes). In total, 37 clusters (containing 272 isolates) were distinguished by primer DAF-4 at the cut-off value of ≥72% similarity (Fig. 1); 15 isolates were classed as sporadic on the grounds that they did not cluster with any other isolate at >72% similarity.

Most clusters comprised <10 isolates; however, there were four large clusters (designated as DAF-4 clusters 3, 10, 14, 32) that each contained ≥20 isolates (Fig. 1). In total, 121 (42%) isolates from 25 hospitals belonged to one of these four major clusters. Two of these major clusters (clusters 10 and 14) contained only Acinetobacter DNA group 2 isolates, whereas the other two (clusters 3 and 32) contained only isolates belonging to Acinetobacter DNA group 13TU. Cluster 3 comprised 23 isolates from 15 hospitals spread throughout England and Wales. Cluster 10 included 38 isolates from 12 hospitals located in the Midlands, West and South-East of England, but most (29 of 38) of the isolates included in this cluster originated from hospitals in London and the South-East. Isolates in cluster 14 were obtained from 11 hospitals in England and Wales, although many (17 of 25) of these isolates were from hospitals in London and the South-East. Isolates in cluster 32 were found in eight hospitals in England, Wales and Scotland, but most (25 of 36) came from two Scottish hospitals. The 166 isolates that did not belong to the four major clusters comprised 33 clusters and 15 sporadic isolates, and were distributed among 42 hospitals in England, Wales and Scotland.

Groups of three or more isolates from a single hospital which displayed the same RAPD fingerprints were considered to be potential outbreak strains. Such organisms were obtained from 13 (28.2%) of the 46 hospitals and comprised 35.5% (102) of the 287 isolates examined. These potential outbreak isolates belonged to 10 DAF-4 clusters (Table 1) and were re-examined with primer ERIC-2 to see whether the same clustering relationships were observed. As found with DAF-4, each isolate tested yielded a reproducible fingerprint pattern with DNA extracts prepared on different days. After merging of gel data, the molecular size standards from each ERIC-2 gel clustered at a level of 92.3% similarity with a band position tolerance of 1% (i.e., above the proposed cut-off value of ≥72% similarity for defining unrelated genotypes). When the clusters obtained with ERIC-2 were compared with those obtained with DAF-4, a high degree of correlation was observed. Thus, for example, each of the three major DAF-4 clusters involved in potential outbreaks (clusters 10, 14 and 32) correlated with a distinct ERIC-2 cluster, indicating that the relationships ob-

![Fig. 1. Dendrogram illustrating the DAF-4 RAPD clustering relationships observed among 287 isolates belonging to Acinetobacter DNA groups 2 and 13TU obtained from UK hospitals. Cluster relationships were calculated with BioNumerics software by the Dice coefficient and UPGMA method. The arrowhead indicates the position of the previously established >72% similarity cut-off point used to differentiate clusters [5, 12]. Clusters labelled 3, 10, 14 and 32 are the four predominant clusters identified with primer DAF-4. Clusters 10 and 14 contained only DNA group 2 isolates, while clusters 3 and 32 contained only DNA group 13TU isolates.](image-url)
served between the potential outbreak isolates were not artefacts generated by the choice of a particular RAPD primer or by the RAPD technique itself. Of the potential outbreak isolates, 69.6% (71 of 102) belonged to these three clusters (Table 1). Of the 38 isolates belonging to DAF-4 cluster 10, 30 (78.9%) were associated with outbreaks of infection in six hospitals. In the case of DAF-4 cluster 14, 13 (52%) of the 25 isolates were associated with outbreaks of infection in two hospitals. Of 36 isolates in DAF-4 cluster 32, 28 (77.8%) came from two Scottish hospitals and one from Wales. The remaining 31 outbreak-associated isolates came from eight hospitals and belonged to seven different clusters (Table 1).

Of note was the fact that none of the potential outbreaks involved isolates belonging to the major DAF-4 cluster 3. Thus, although isolates in this cluster were isolated from 15 hospitals throughout England and Wales, there was no evidence for this lineage causing outbreaks of infection within individual hospitals. However, when DAF-4 cluster 3 was re-examined with primer ERIC-2, three ERIC-2 sub-clusters were found, indicating that the isolates in DAF-4 cluster 3 may be more diverse than suggested by RAPD fingerprinting with DAF-4 alone.

### Antimicrobial susceptibilities

More than 80% of the isolates included in the study were resistant to cefotaxime, ceftazidime and tetracycline, but most isolates remained susceptible to carbapenems and colistin, which are the agents currently used to treat most multi-drug-resistant Acinetobacter infections (Table 2). Outbreak-related isolates showed higher rates of resistance to all antibiotics tested, with the exceptions of colistin and sulbactam; however, this difference was not significant for any antibiotic considered (p > 0.05 in each case).

Some minor variations in resistance profiles were observed among isolates belonging to the same cluster. Within the four main DAF-4 clusters, isolates were generally resistant to cephalosporins, penicillins and

### Table 1. Distribution of outbreak-associated Acinetobacter DNA group 2 and 13TU isolates

<table>
<thead>
<tr>
<th>Genomic species</th>
<th>Total number of isolates outbreaks</th>
<th>Number of hospitals with outbreaks</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAF-4 cluster</td>
<td>SE</td>
<td>E</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>38</td>
</tr>
<tr>
<td>13</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>21</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>23</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>32</td>
<td>13TU</td>
<td>36</td>
</tr>
</tbody>
</table>

SE, London and South-East England; E, East of England; Mid, Midlands; SW, South-West England; N, North of England; Sco, Scotland; Wal, Wales.

### Table 2. Prevalence of antibiotic resistance among Acinetobacter DNA group 2 and 13TU isolates from UK hospitals

<table>
<thead>
<tr>
<th>Antibiotic</th>
<th>Total (n = 287)</th>
<th>Outbreak-related (n = 102)</th>
<th>Non-outbreak related (n = 185)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amikacin</td>
<td>23.1</td>
<td>27.5</td>
<td>20.5</td>
</tr>
<tr>
<td>Ciprofloxacin</td>
<td>48.4</td>
<td>60.8</td>
<td>41.6</td>
</tr>
<tr>
<td>Colistin</td>
<td>1.1</td>
<td>0</td>
<td>1.6</td>
</tr>
<tr>
<td>Cefotaxime</td>
<td>95.0</td>
<td>100</td>
<td>92.4</td>
</tr>
<tr>
<td>Ceftazidime</td>
<td>87.2</td>
<td>96.0</td>
<td>82.1</td>
</tr>
<tr>
<td>Gentamicin</td>
<td>45.6</td>
<td>55.9</td>
<td>40.0</td>
</tr>
<tr>
<td>Imipenem</td>
<td>1.8</td>
<td>2.9</td>
<td>1.1</td>
</tr>
<tr>
<td>Meropenem</td>
<td>0.7</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td>Piperacillin</td>
<td>69.8</td>
<td>86.3</td>
<td>60.5</td>
</tr>
<tr>
<td>Piperacillin/tazobactam</td>
<td>40.4</td>
<td>49.0</td>
<td>35.7</td>
</tr>
<tr>
<td>Sulbactam</td>
<td>11.7</td>
<td>9.8</td>
<td>13.0</td>
</tr>
<tr>
<td>Tetracycline</td>
<td>86.5</td>
<td>89.2</td>
<td>84.9</td>
</tr>
</tbody>
</table>

*Susceptibilities were interpreted with the breakpoints recommended for Acinetobacter spp. by the British Society for Antimicrobial Chemotherapy [10, 11]. Differences in the prevalence of resistance between outbreak-related and non-outbreak isolates were not significant (p > 0.05).*
tetracycline, with isolates belonging to clusters 10 and 14 additionally showing resistance to aminoglycosides and quinolones. Isolates not belonging to the four major clusters varied from fully sensitive to highly resistant, but the isolate numbers in the individual clusters were too small to allow firm conclusions to be reached. Three outbreak-associated isolates in cluster 10 (all from a single hospital) and two non-outbreak isolates in cluster 14 were resistant to imipenem. Two isolates from different hospitals (one outbreak-related isolate belonging to cluster 10 that was also imipenem-resistant, and one non-outbreak isolate in cluster 13) were resistant to meropenem.

Discussion

As reported previously [4–6], RAPD fingerprinting was found to be a reliable and reproducible typing technique for *Acinetobacter* DNA group 2 and 13TU isolates. It is important to note that the highly standardised methodology [13] employed in this study is essential to achieve the necessary level of reproducibility with the RAPD technique. However, providing that the technique is carefully standardised, it has been established previously [4] that RAPD typing of *Acinetobacter* spp. provides robust results that are comparable with those obtained by other typing techniques such as pulsed-field gel electrophoresis. In comparison, conventional phenotypic tests are generally inadequate even to distinguish between different *Acinetobacter* DNA groups [1], while biotyping gives poor discrimination between individual strains of DNA groups 2 and 13TU [4].

The RAPD typing results obtained in the study indicated that there was a heterogeneous population of *Acinetobacter* DNA group 2 and 13TU isolates in the UK hospitals studied. However, four main clusters of isolates were found within this population, and members of three of these clusters were implicated in outbreaks of infection in particular locations, in addition to being isolated sporadically at other locations. For example, of the 22 isolates examined from a single hospital in Scotland, 18 belonged to DAF-4 cluster 32 when analysed by RAPD fingerprinting. Isolates in this cluster, all of which belonged to *Acinetobacter* DNA group 13TU, were also found at a second hospital in Scotland and one in Wales. A previous study similarly identified a single strain of *Acinetobacter* DNA group 13TU as the main cause of *Acinetobacter* infections in Edinburgh Royal Infirmary over a 3-year period in the 1990s [14]. In contrast, other hospitals appeared to have diverse populations of *Acinetobacter* DNA group 2 and 13TU isolates. For example, of 15 isolates examined from a hospital in the Midlands, 13 belonged to different clusters, suggesting that there were a number of different strains circulating in this particular hospital that were capable of causing infections. Similar contrasting epidemiological relation- ships among *Acinetobacter* isolates from different geographical locations have been reported previously [15], possibly reflecting patient mix or the efficiency of different local control of infection policies and procedures.

Three of the four major clusters identified in this study seemed to have spread in specific regions of the country. For example, isolates in DAF-4 cluster 32 were predominantly collected from Scottish hospitals, whereas isolates in DAF-4 clusters 10 and 14 were found mainly in hospitals in London and the South-East of England. DAF-4 cluster 3 appeared to be different from the other predominant clusters, in that its constituent isolates were not concentrated in any specific region of the country. Furthermore, the isolates in this cluster were not associated with outbreaks of infection in individual hospitals, initially suggesting that not all widely disseminated strains of *Acinetobacter* DNA group 2 or 13TU are equally capable of causing such outbreaks. However, further RAPD typing experiments with primer ERIC-2 revealed evidence for a limited amount of diversity within the cluster, indicating that this cluster was not as homogeneous as suggested by RAPD typing with a single primer.

The evidence of inter-hospital spread of *Acinetobacter* DNA group 2 and 13TU strains supports the conclusions of several other European studies that have examined the epidemiology of *A. baumannii* [3, 16]. However, the potentially ‘epidemic’ strains circulating in UK hospitals do not seem to be the same as the two major epidemic strains found in other European countries (personal unpublished data). Furthermore, a recent RAPD fingerprinting study of *A. baumannii* isolates from 49 medical centres across the USA found no evidence of inter-hospital spread [6]. Additional studies are required to determine whether these differences are strain-related or a consequence of specific infection control measures and antibiotic policies implemented in different locations.

As in previous studies of *Acinetobacter* spp. [6, 7, 17–19], many of the nosocomial *Acinetobacter* DNA group 2 and 13TU isolates in the present study were found to be multiresistant. Strains that predominate in certain hospitals or regions may possess characteristic features that enable them to out-compete other strains. Multiple antibiotic resistance is one such factor that might be expected to give a selective advantage in spread of particular strains [3, 20]. However, two of the main clusters (DAF-4 clusters 3 and 32) identified in the present study were not highly antibiotic-resistant but, notably, belonged to *Acinetobacter* DNA group 13TU rather than *A. baumannii*. The significance of this observation is hard to assess at present, because most previous studies have not distinguished between DNA groups 2 and 13TU, and little is known about the general epidemiology of 13TU isolates. The two other main clusters, comprising isolates of *A. baumannii*,...
were generally multiresistant. Resistance to carbapenems was confined to six isolates belonging to three clusters (10, 13 and 14) from two hospitals in the South-East of England and one in the North-West. Three of these isolates (all belonging to cluster 10) were outbreak-associated, but carbapenem resistance was not found in the remaining 35 isolates belonging to the same cluster, suggesting that resistance was appearing in individual patients who had already acquired the outbreak strain.

It has been proposed that the ability of particular strains to cause outbreaks within and between hospitals is likely to be multifactorial and related to factors other than the simple possession of antibiotic resistance mechanisms. Thus, Koellemann et al. [20] reported that multiple antibiotic resistance and the ability to bind to salivary mucus both correlated with the epidemic behaviour of A. baumannii isolates. It is also probable that the ability of particular strains to survive for long periods in the hospital environment enhances their chances of transmission [21, 22]. Nevertheless, certain antibiotic resistance determinants, once acquired, may favour repeated selection of specific strains in the hospital setting. Other possible factors involved in determining the outbreak potential of strains remain to be elucidated.

We are indebted to colleagues at all the clinical microbiology laboratories that collected the strains included in the study, to L. Dijkshoorn for the gift of strain RUH 2037, and to T. van der Reijden for teaching R.P.S. the AFLP fingerprinting technique.

References